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APPLICATION OF THE U.S. GEOLOGICAL SURVEY'S PRECIPITATION—RUNOFF MODELING SYSTEM TO WILLIAMS DRAW AND BUSH DRAW BASINS, JACKSON COUNTY, COLORADO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 88-4013

Prepared in cooperation with the
U.S. BUREAU OF LAND MANAGEMENT

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Denver, Colorado
1988

DEPARTMENT OF THE INTERIOR

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U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

The following factors can be used to the convert inch-pound units in this report to metric (International Systems) units:

Multiply inch-pound unit	*By*	*To obtain metric unit*
acre-foot (acre-ft)	1233	cubic meter
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

To convert degree Fahrenheit (°F) to degree Celsius (°C), use the following formula: °C = 5/9 (°F - 32).

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

APPLICATION OF THE U.S. GEOLOGICAL SURVEY'S PRECIPITATION-RUNOFF MODELING SYSTEM TO WILLIAMS DRAW AND BUSH DRAW BASINS, JACKSON COUNTY, COLORADO

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ABSTRACT

The U.S. Geological Survey's precipitation-runoff modeling system was calibrated for this study by using daily streamflow data for April through September, 1980 and 1981, from the Williams Draw basin in Jackson County, Colorado. The calibrated model then was verified by using daily streamflow data for April through September, 1982 and 1983. Transferability of the model was tested by application to adjoining Bush Draw basin by using daily streamflow data for April through September, 1981 through 1983.

Four model parameters were optimized in the calibration: (1) BST, base air temperature used to determine the form of precipitation (rain, snow, or a mixture); (2) SMAX, maximum available water-holding capacity of the soil zone; (3) TRNCF, transmission coefficient for the vegetation canopy over the snowpack; and (4) DSCOR, daily precipitation correction factor for snow.

For calibration and verification, volume and timing of simulated streamflow compared closely to recorded streamflow; differences were least during years that had considerable snowpack accumulation and were most during years that had minimal or no snowpack accumulation. Calibration of the model was facilitated by snowpack water-equivalent data.

Application of the model to Bush Draw basin to test for transferability indicated inaccurate results in simulation of streamflow volume. Weighted values of SMAX, TRNCF, and DSCOR from the calibration basin were used for Bush Draw. The inadequate results obtained by use of weighted parameters indicate that snowpack water-equivalent data are needed for successful application of the precipitation-runoff modeling system in this area, because frequent windy conditions cause variations in snowpack accumulation.

INTRODUCTION

Much of the concern about coal-resources development on Federal land is how it affects local water resources. Questions regarding effects on local water resources occur as development proceeds or as new areas are proposed for development. Often, minimal or no hydrologic information is available for areas of active or proposed coal-resource development. Moreover, the length of time required to obtain enough information to determine the hydrologic effects of coal-resource development may be several years, especially in the semiarid West, where coal areas primarily are drained by ephemeral streams.

In an effort to minimize the time required to obtain at least some surface-water hydrologic information for Federal coal areas, the U.S. Geological Survey and the U.S. Bureau of Land Management began a cooperative study in 1976 to develop, test, and verify a hydrologic model. The goals of the model development were to provide: (1) A method to estimate the hydrologic characteristics and processes for areas where basic hydrologic data are lacking, and (2) the capability to predict hydrologic effects from potential coal-lease areas (Van Haveren and Leavesley, 1979, p. 4). The model, the precipitation-runoff modeling system (PRMS), is described in detail in Leavesley and others (1983). In conjunction with the model development, small basins in coal areas on Federal land were instrumented and studied to provide the data necessary to test the model (Van Haveren and Leavesley, 1979, p. 8).

Purpose and Scope

As part of the study of small basins in coal areas on Federal land, Williams Draw and Bush Draw basins in Jackson County, Colorado (fig. 1), were instrumented and studied to test PRMS. The purpose of this report is to present the results of the application of the model to these two basins. Williams Draw was instrumented beginning in July 1979, and streamflow, precipitation, and snowpack water-equivalent data were collected. Bush Draw was instrumented beginning in October 1980, but only streamflow data were collected. However, streamflow data were obtained only for April through September at both locations because there was no runoff during the winter months. The purpose of the data obtained for Williams Draw basin was to provide the data necessary to calibrate and verify the model. The data obtained for Bush Draw basin were used to test the transferability of the calibrated model.

The small-basin study in Jackson County was part of a larger, ongoing study conducted by the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management (U.S. Geological Survey, 1984b, p. 27) to provide baseline hydrologic information for coal-resource areas drained by the Canadian River (fig. 1). Data collection for the study ended during September 1983. Streamflow and water-quality data from the studies have been published in annual reports (U.S. Geological Survey, 1980-1984a). Water-quality data also were summarized statistically by Kuhn (1982). A preliminary evaluation of the hydrology of Williams Draw basin and adjacent areas was presented in a resource and potential reclamation evaluation report (U.S. Bureau of Land Management, 1983, p. 93-118). A more general description of the hydrology and coal resources of the area was presented in one of a nationwide series of reports describing the hydrology of coal-resource areas (Kuhn and others, 1983).

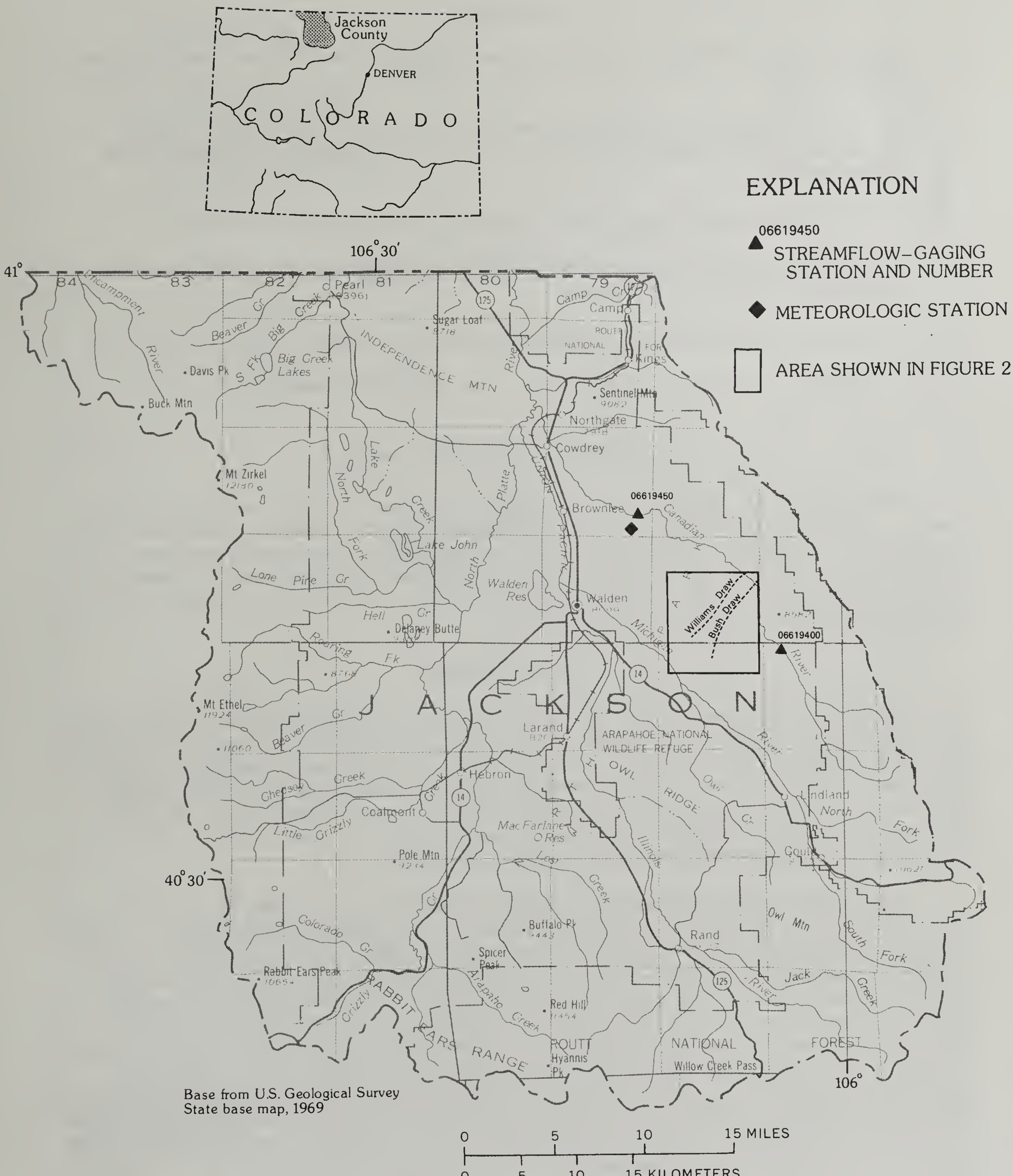

Figure 1.--Location of Williams Draw and Bush Draw in Jackson County.

Approach

Application of PRMS to Williams Draw and Bush Draw basins consisted of five basic steps:

1. Collection of streamflow, precipitation, air-temperature, solar-radiation, and snowpack water-equivalent data needed for application of the model;

2. Partitioning of each basin into hydrologically similar units;

3. Estimation of model parameters and selection of parameters to be optimized during calibration;

4. Calibration and verification of the model; and

5. Testing for transferability of the calibrated model.

DESCRIPTION OF STUDY AREA

The study area (fig. 1) is located in the east-central part of Jackson County. Most of Jackson County coincides with North Park, an intermontane basin in the Southern Rocky Mountains physiographic province (Fenneman, 1931, p. 125-127). Because the study area is within North Park, which consists of a topographically and climatologically uniform area, frequent reference to North Park will be used in this report.

General Features

North Park generally is a 1,000-mi^2 gently rolling, treeless area that has elevations ranging from about 8,000 to 8,500 ft. Elevations in the study area are between about 8,110 ft and 8,400 ft, with a small, isolated ridge that has a maximum elevation of about 8,550 ft. Williams Draw basin has a drainage area of 3.95 mi^2 (at streamflow-gaging station 06619420 Williams Draw near Walden), and Bush Draw basin has a drainage area of 4.10 mi^2 (at station 06619415 Bush Draw near Walden) (fig. 2).

The basins are elongated considerably and the main channels of both streams, as well as most tributary channels, are relatively straight. Direction of flow generally is to the northeast. Williams Draw basin has a pronounced asymmetry (fig. 2), because the main channel is near the southeast border of the basin. The majority of the basin is northwest of the main channel, where the drainage network is extensive and overall slopes are relatively moderate; only a small part of the basin is southeast of the main channel, where the drainage network is minimal and slopes are relatively steep. Bush Draw basin, by contrast, is considerably symmetrical (fig. 2), the main channel is near the center of the basin, and the drainage network is not very extensive. Overall slopes also are relatively moderate northwest of the main channel and relatively steep southeast of the channel in Bush Draw basin. Both streams are tributaries of the Canadian River (fig. 1). A detailed physiographic description of Williams Draw basin is presented in a report by the U.S. Bureau of Land Management (1983, p. 49-62).

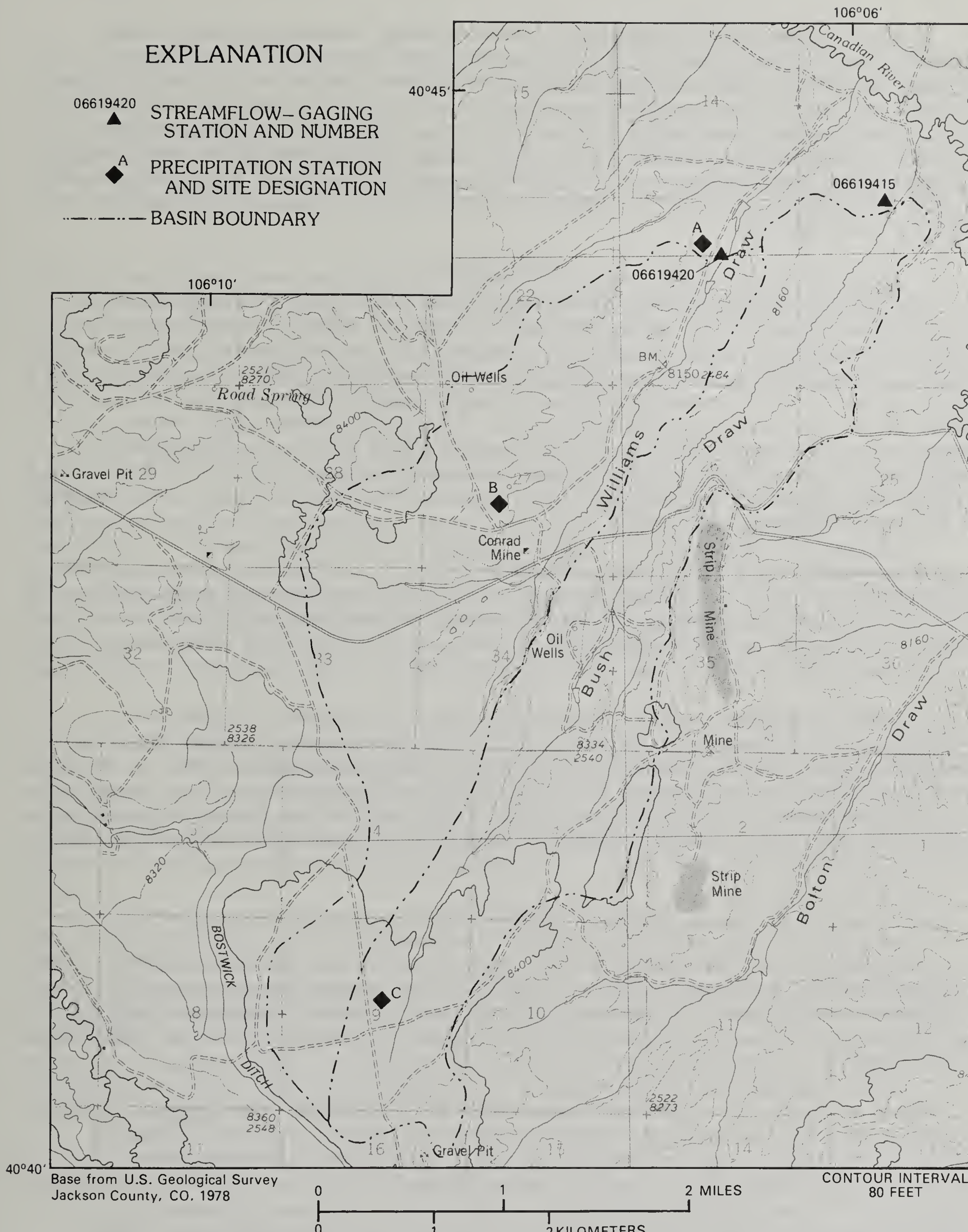

Figure 2.--Location of streamflow-gaging and precipitation stations in Williams Draw and Bush Draw basins.

The Cretaceous Pierre Shale, the coal-bearing Coalmont Formation of Tertiary age, and the Quaternary terrace deposits crop out in the area. Outcropping of the Pierre Shale and Coalmont Formation is controlled largely by the north-northwest trending McCallum anticline that traverses the center of the study area. The Coalmont Formation crops out on the flanks of the anticline, and the Pierre Shale crops out in the center where the overlying Coalmont Formation has been eroded away. Quaternary terrace deposits composed of sand and gravel overlie the other two formations in some of the higher areas (Kinney, 1970).

A detailed study of the soils of Jackson County has been completed by the U.S. Soil Conservation Service (Fletcher, 1981). This soil survey indicates that primarily three soil units--the Gelkie and the Morset series, and the steep Cryorthents--have been mapped in the study area (Fletcher, 1981, pls. 13 and 14). These soils are classified as loams or sandy loams. The Gelkie and Morset series are characterized by soil depths greater than 20 in. and a runoff potential that is low to moderate, whereas the steep Cryorthents are characterized by soil depths generally less than 20 in. and are subject to rapid runoff and severe wind and water erosion (Fletcher, 1981, p. 18-19). Several other soil units also have been mapped, but they are not as extensive as the three primary soil units.

A study by the U.S. Bureau of Land Management was done to determine the suitability of soils in and adjacent to the study area for use as planting media for resurfacing shaped spoils following surface mining. Results of that study (U.S. Bureau of Land Management, 1983, p. 69) indicated that about 87 percent of the soils in the area are suitable.

Vegetation in the area is composed entirely of shrubs (primarily *Artemesia* sp.) and grasses. On the basis of a vegetation study of Williams Draw basin and adjacent areas (U.S. Bureau of Land Management, 1983, p. 77-92), seven ecological subdivisions, or range sites, are within the area: mountain loam, dry mountain loam, drainage bottom, clay pan, valley bench, dry exposure, and salt flat. These subdivisions are mapped and described in detail in the previous reference.

Climate

An analysis of the climate of Williams Draw basin and adjacent areas was completed by McKee and others (1981) for the resource and potential reclamation evaluation of the area (U.S. Bureau of Land Management, 1983). The following discussion is wholly derived from the climate study by McKee and others (1981).

Much of North Park, including Williams Draw and Bush Draw basins, is characterized by a generally uniform, semiarid climate, with cool summers and cold winters. Large variations in daily and seasonal temperatures are common. Daily temperature variations are about 25 °F in winter but increase to about 40 °F in midsummer and fall. Temperature extremes measured at Walden, about 8 mi west of Williams Draw and at a similar elevation, were 96 °F and -49 °F between 1938 and 1978. During that period, average July temperature was 59 °F, and average January temperature was 15 °F; average July maximum temperature was 78 °F, and average January minimum temperature was 3 °F.

Annual precipitation at Walden averaged about 10 in. between 1938 and 1978; annual precipitation in the study area of the two basins probably is about 11 to 12 in. About 60 percent of the annual precipitation occurs during May through September; precipitation from October through April usually is in the form of snow. Daily precipitation quantities greater than 1 in. are unusual, especially during the summer, when most precipitation results from thunderstorms. On the average, rainfall quantities greater than 0.1 in. occur only 18 days each summer.

Streamflow

Two streamflow-gaging stations, station 06619420 Williams Draw near Walden and station 06619415 Bush Draw near Walden (fig. 2), were established to obtain continuous records of streamflow for this modeling study. Streamflow in the two basins is ephemeral and, as previously described, streamflow records were obtained only from April through September.

Hydrographs of average daily streamflow at station 06619420 (Williams Draw) for the 1980, 1982, and 1983 runoff periods are shown in figure 3; no streamflow was recorded during the 1981 runoff period nor during the July through September 1979 period. Recorded streamflow in Williams Draw was not very large. The maximum daily streamflow was 11 ft^3/s (fig. 3); maximum instantaneous streamflow was 22 ft^3/s (U.S. Geological Survey, 1984a, p. 50). Recorded streamflow volumes were 123 acre-ft in 1980, 4.7 acre-ft in 1982, and 112 acre-ft in 1983. [Note: Streamflow volume in acre-feet is obtained by summing the daily streamflows, in cubic feet per second, and multiplying the sum by the conversion factor of 1.9835.]

A hydrograph of average daily streamflow at station 06619415 (Bush Draw) for the 1983 runoff period is shown in figure 4. Only 1 day of very small streamflow was recorded during the 1981 runoff period and no flow was recorded during the 1982 runoff period. During the 1983 runoff period, the maximum daily streamflow at station 06619415 was 4.0 ft^3/s (fig. 4) and maximum instantaneous streamflow was 42 ft^3/s (U.S. Geological Survey, 1984a, p. 49). Streamflow volume for 1983 was 69 acre-ft.

Nearly all streamflow recorded at stations 06619420 and 06619415 during the study period resulted from snowmelt during April and May. During the summer of 1983, one of the wettest summers on record, considerable streamflow resulting from rainfall was recorded (figs. 3 and 4). However, the volume of streamflow resulting from rainfall during June, July, and August was small in comparison to the volume of streamflow resulting from snowmelt. During 1983, about 80 percent of the recorded streamflow at station 06619420 and about 75 percent of the recorded streamflow at station 06619415 resulted from snowmelt during April and May.

MODEL DESCRIPTION

PRMS is a deterministic physical-process model that is capable of simulating the response (for example, streamflow) of a hydrologic system (a basin or watershed) to the model input (for example, precipitation and land use).

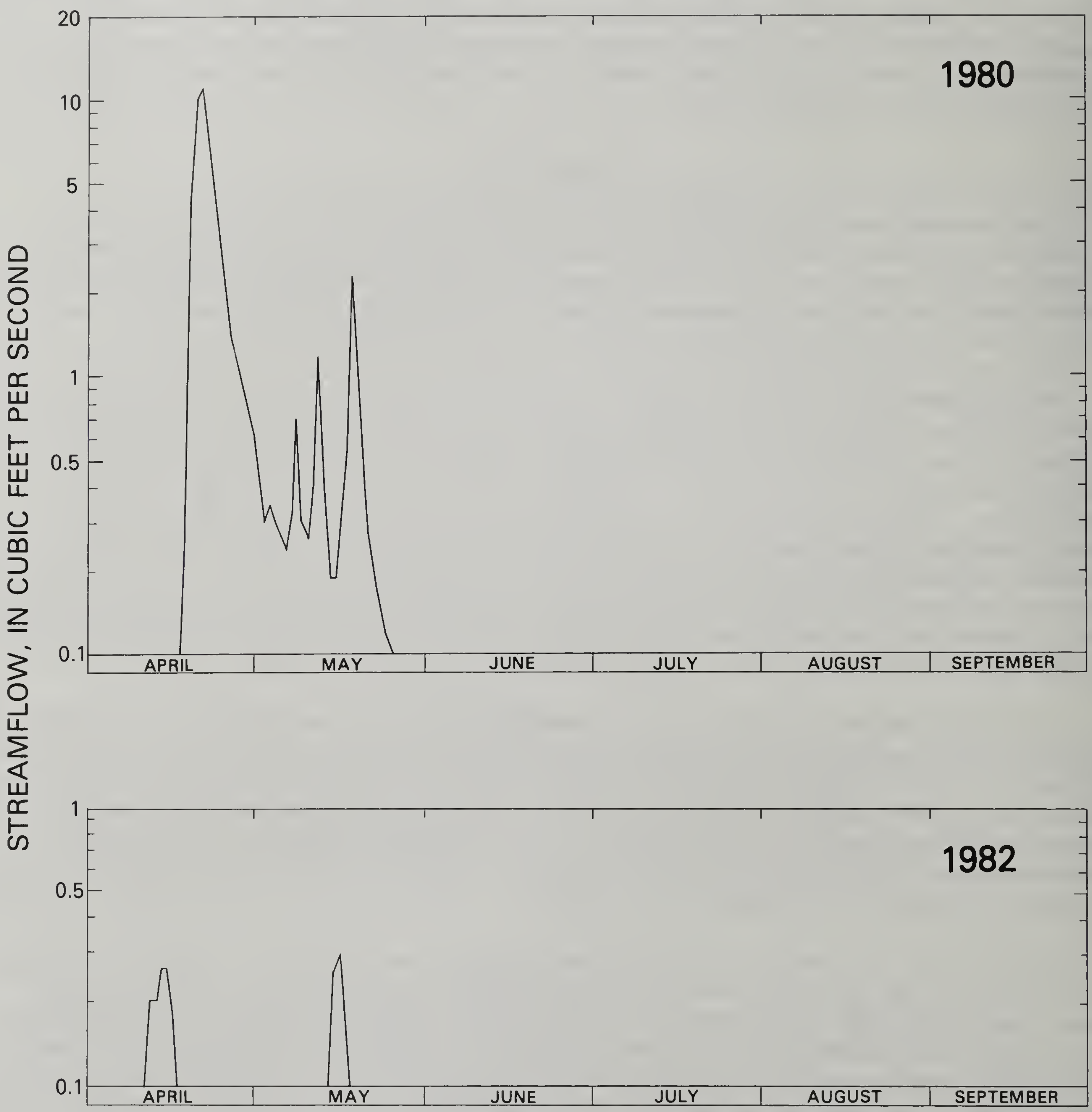

Figure 3.--Daily average streamflow at station 06619420 Williams Draw near Walden, 1980-83.

Changes in the response that result from differences in the hydrologic system, whether real or hypothetical, also can be simulated by making appropriate modifications to the model input. The model is designed to function either as a lumped- or distributed-parameter model and has the capability to simulate average daily streamflow or stormflow hydrographs.

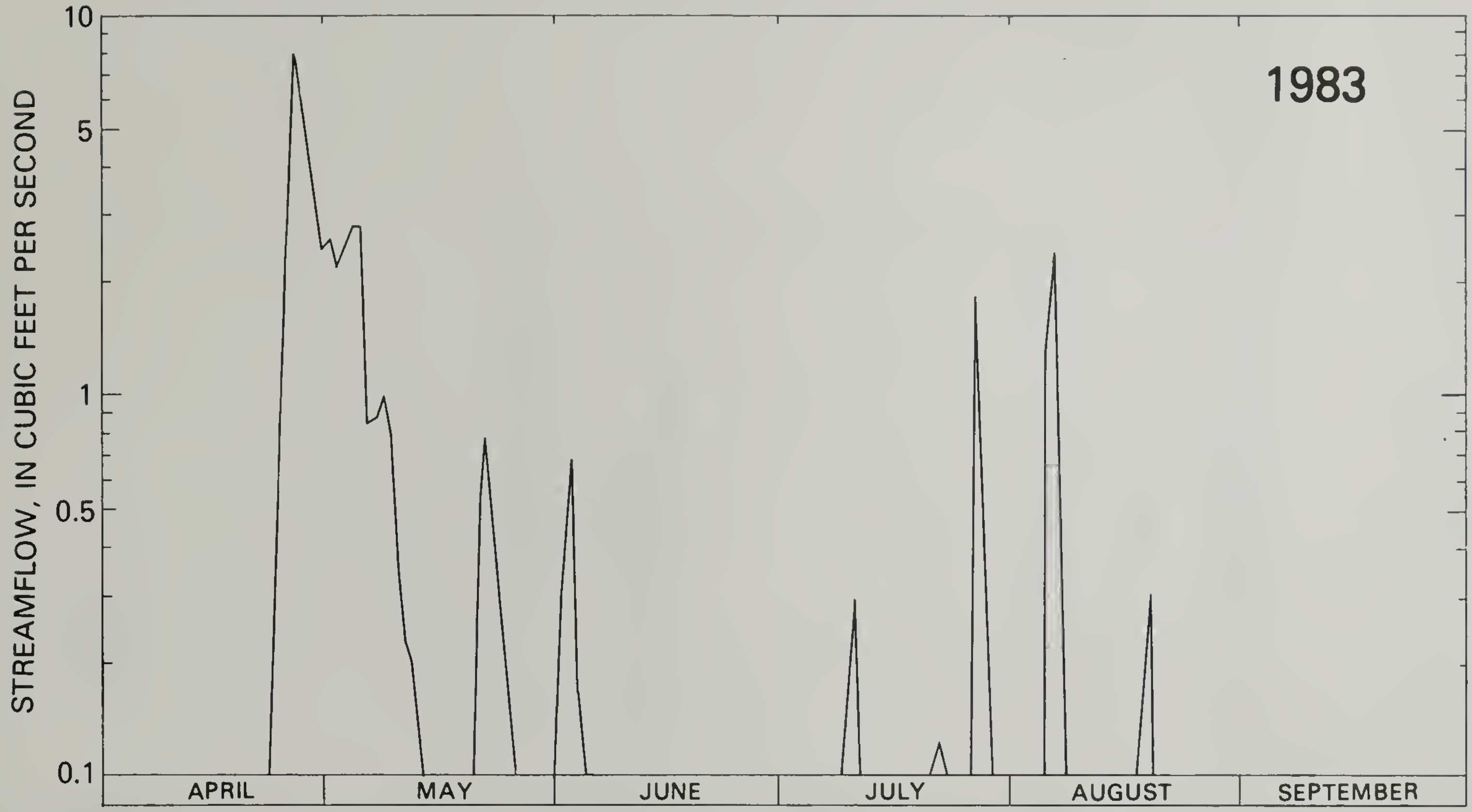

Figure 3.--Daily average streamflow at station 06619420 Williams Draw near Walden, 1980-83--Continued.

Development and operation of PRMS is based on a conceptual watershed system (fig. 5). The various components of the watershed system (hydrologic cycle) are represented mathematically in the model by known physical laws or empirical relations, which attempt to reproduce the physical reality of the hydrologic system as nearly as possible. Inputs to the watershed system are precipitation, air temperature, and solar radiation. Precipitation, in the form of rain, snow, or a mixture of the two, is delivered to the watershed; the inputs of air temperature and solar radiation drive the processes of evaporation, transpiration, sublimation, and snowmelt (Leavesley and others, 1983, p. 7). Thus, daily values for precipitation, air temperature, and solar radiation are needed to operate the model.

The conceptual watershed system (fig. 5) includes four reservoirs: the upper soil zone, the subsurface, the ground water, and the impervious zone. Outputs of these reservoirs combine to produce the total system response. In this report, the impervious-zone reservoir was not considered because it was not applicable to Williams Draw and Bush Draw basins.

The upper soil-zone reservoir is two-layered; it represents the part of the soil mantle that can lose water through the processes of evaporation and transpiration. The quantity of water stored in the upper soil-zone reservoir is increased by infiltration of rainfall or snowmelt; if rainfall or snowmelt exceed specific infiltration rates, then surface runoff (Q_1, fig. 5) results. Some of the excess infiltration also can be routed to the subsurface

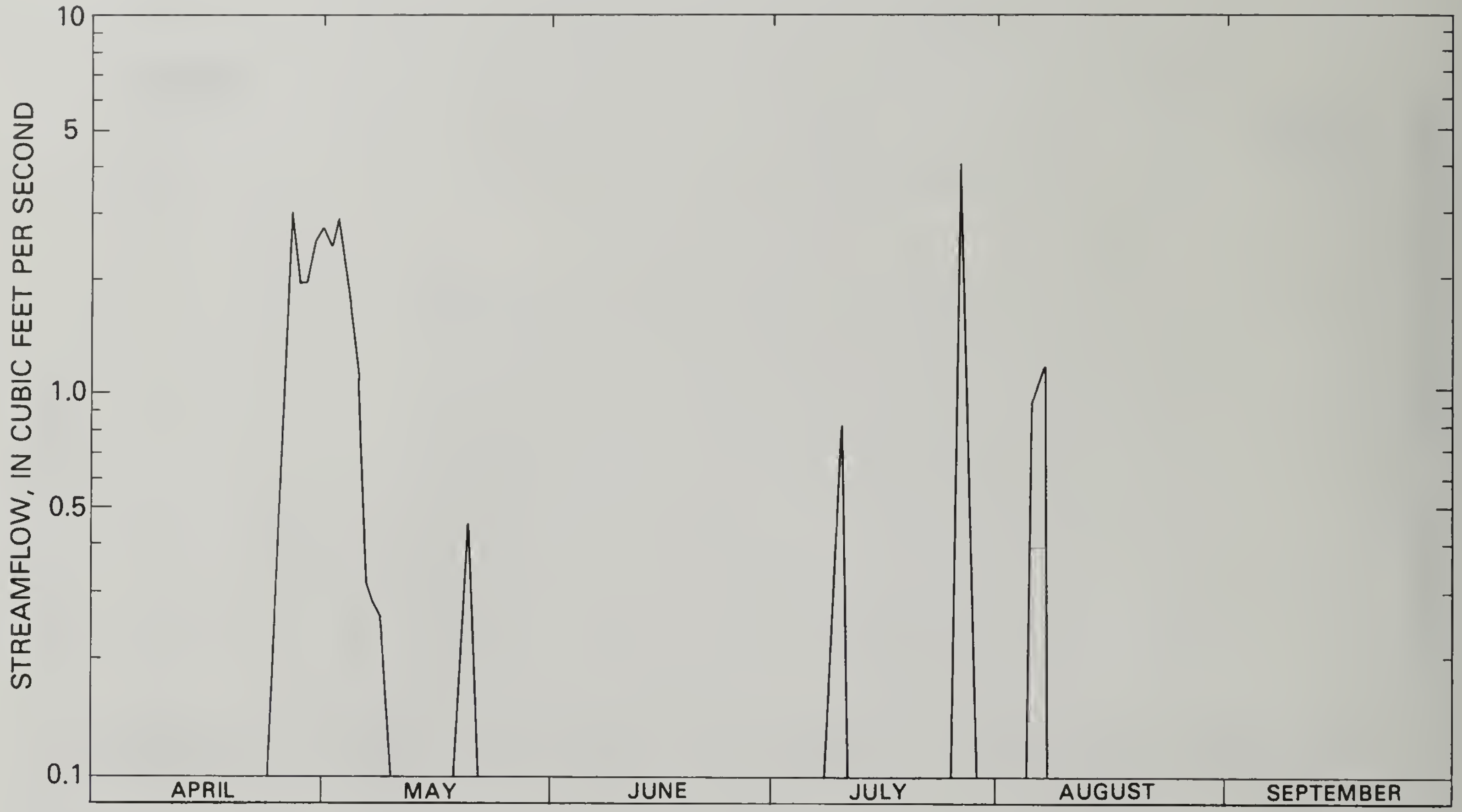

Figure 4.--Daily average streamflow at station 06619415 Bush Draw near Walden, 1983.

reservoir. Subsurface flow (Q_2) is derived from water in shallow ground-water zones (subsurface reservoirs) that is available for relatively rapid movement to a channel system. The ground-water reservoir, which is the source of all baseflow (Q_3), can be recharged from either the soil-zone reservoir or the subsurface reservoir, or from both. Water from the ground-water reservoir also can be routed to a ground-water sink beyond the area of measurement. Streamflow (Q_4) is the sum of Q_1, Q_2, and Q_3. A more detailed description of the conceptual watershed system is provided by Leavesley and others (1981; 1983, p. 7-9).

For simulation of average daily streamflow, which was used in the present study, watersheds are divided into any number of hydrologic-response units (HRU's). HRU's are delineated on the basis of similarities in such characteristics as slope, aspect, elevation, type of vegetation, type of soil, and precipitation. Partitioning a watershed into HRU's provides the capability to account for spatial and temporal variations in physical and hydrologic characteristics, climatic variables, and system responses within a watershed. The sum of the responses of all HRU's, weighted on a unit-area basis, produces the daily watershed response and streamflow (Leavesley and others, 1983, p. 9).

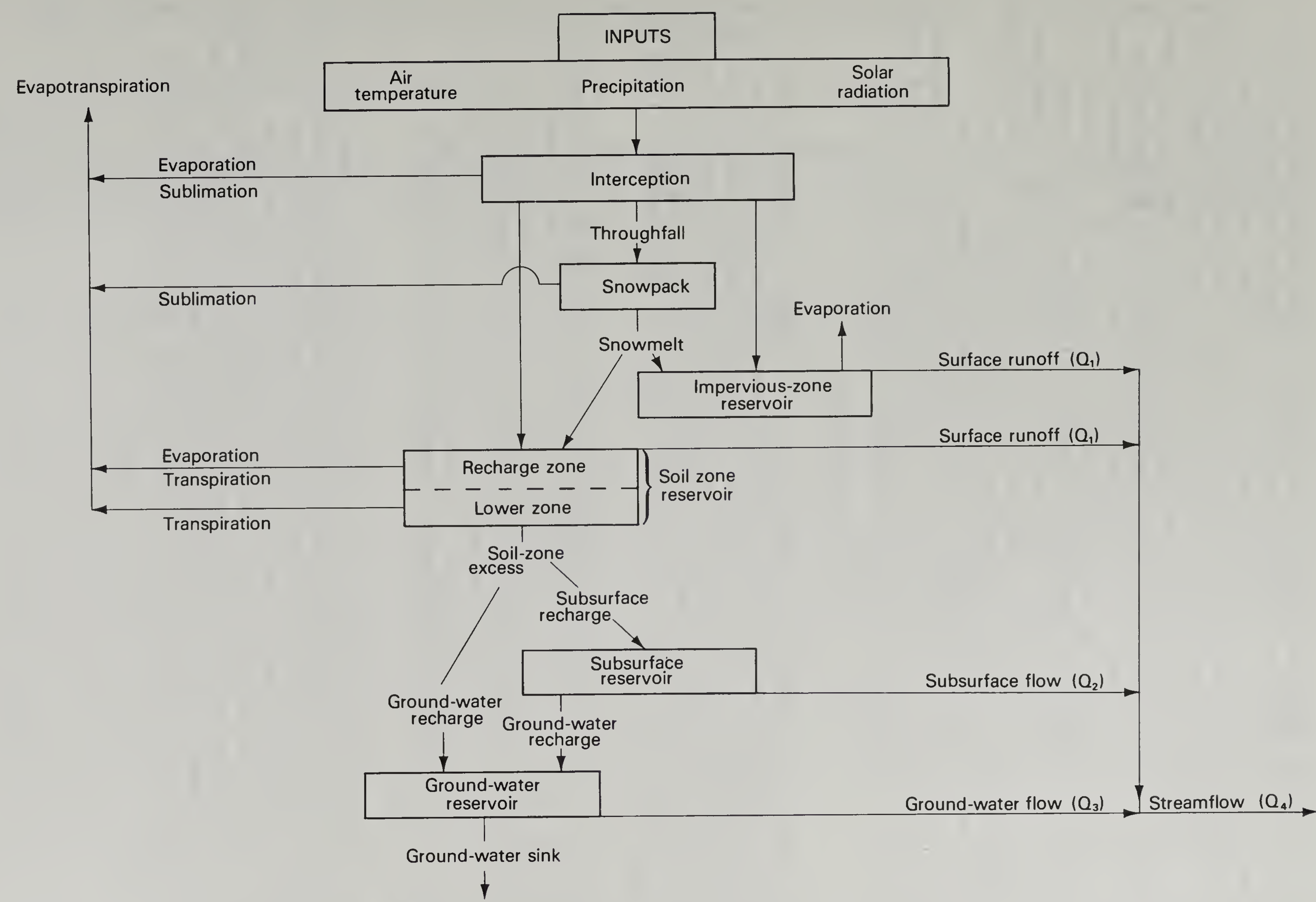

Figure 5.--The conceptual watershed system and its inputs (modified from Leavesley and others, 1983, p. 8).

APPLICATION OF MODEL TO WILLIAMS DRAW AND BUSH DRAW BASINS

Application of PRMS to Williams Draw and Bush Draw basins consisted of several steps. The first step was the collection of daily streamflow, precipitation, air-temperature, solar-radiation, and snowpack water-equivalent data. Streamflow data have been previously described; meteorological data are described in subsequent paragraphs. The second step consisted of HRU delineation on the basis of physical or hydrological similarities of various parts of the basin. Initial values for model parameters then were determined or were determined in conjunction with delineation of the HRU's; the model parameters to be optimized during calibration also were selected. The model was calibrated for Williams Draw basin by using streamflow data for April through September, 1980 and 1981, and then was verified by using streamflow data for April through September, 1982 and 1983. The period from July 1979 to April 1980 was used as an initialization period for the model. After calibration and verification, the sensitivity of optimized parameters was analyzed. Lastly, the transferability of the model was tested for Bush Draw basin by using streamflow data for April through September, 1981 through 1983. The following discussion is a more detailed description of this process.

Meteorological Data

Two precipitation stations (stations A and B, fig. 2) initially were installed in the study area in July 1979 when streamflow-gaging station 06619420 was established on Williams Draw. One precipitation station was at the Williams Draw basin outlet; the other precipitation station was near the center of the basin at a higher elevation. A third precipitation station (station C, fig. 2) was installed in October 1980 near the drainage divide at the southern end of the basin.

Analysis of the precipitation data indicated that variations in daily precipitation during winter at the three stations were not very large. Variations in daily precipitation during summer were more pronounced, but monthly precipitation generally was uniform even during summer (table 1). Therefore, precipitation data from only one of the three stations, station B (fig. 2), were used for model input. However, when daily precipitation quantities at the three stations varied substantially, the average of all stations was used.

Most precipitation stations have a gage-catch deficiency, especially when precipitation is accompanied by wind. Gage-catch deficiency and the use of shields to minimize this deficiency has been discussed extensively in the literature; a brief review of some of this literature is presented by Larson and Peck (1974). The precipitation stations installed in the study area were shielded to minimize gage-catch deficiency, primarily in reference to snowfall. Nevertheless, even if precipitation was uniform throughout a basin, gage-catch deficiency would result in some error in the precipitation data (model input).

Table 1.--*Summary of precipitation data at three locations in Williams Draw and Bush Draw basins, 1980-83 water years*

Precipitation station (fig. 2)	Recorded precipitation, in inches: October	November	December	January	February	March	April	May	June	July	August	September	Water-year total (inches)
						1980 water year							
A	0.92	0.68	0.46	2.27	0.53	0.68	0.45	2.79	0.05	0.44	0.84	1.31	11.42
B	.65	.64	.43	1.92	.57	.68	.51	2.85	.05	.45	.95	1.31	11.01
						1981 water year							
A	1.02	0.48	0.19	0.20	0.65	1.08	0.54	2.95	1.65	2.21	1.03	1.21	13.21
B	.96	.47	.21	.16	.69	1.13	.63	2.77	1.44	1.70	.54	1.93	12.63
C	.78	.37	.18	.17	.50	1.08	.70	2.68	1.20	1.88	1.02	1.67	12.23
						1982 water year							
A	1.22	0.50	0.74	0.85	0.20	0.89	0.67	2.64	0.30	1.35	0.90	2.25	12.51
B	1.11	.58	.73	.72	.19	.86	.57	2.14	.43	1.48	1.20	2.02	12.03
C	1.16	.53	.76	.67	.17	.90	.41	2.03	.52	1.09	1.24	1.97	11.45
						1983 water year							
A	0.75	0.79	0.98	0.23	0.23	1.20	1.84	1.42	2.23	4.26	1.95	0.40	16.28
B	.80	.90	.71	.29	.48	.96	1.73	1.40	2.61	3.69	2.74	.47	16.78
C	.75	.72	.56	.22	.42	.82	1.74	1.15	2.50	3.52	2.20	.55	15.15

Because gage-catch deficiency generally is larger for solid precipitation (snow) than for liquid precipitation (rain) (Larsen and Peck, 1974, p. 857-858) and because most streamflow in the study area results from snowmelt, estimation of snow-catch deficiency for the precipitation stations used in this study (fig. 2) would be important in application of PRMS. Snowpack water-equivalent data, which also was obtained for this study, provided the capability to partially account for snow-catch deficiency. More importantly, however, the snowpack water-equivalent data provided the capability to partially account for the redistribution of snowfall, which was substantial because of the frequent windy conditions common to the study area during winter. Application of the snowpack water-equivalent data is described in the "Model Parameters" section of this report. No data were available in the present study to account for rain-catch deficiency, but the resultant error in rainfall data probably would be no greater than the areal variability in rainfall. Moreover, streamflow resulting from rainfall was not large for either Williams Draw or Bush Draw (figs. 3 and 4).

Air-temperature data for this study were obtained from a meteorological station established in October 1979 about 12 mi northwest of the study area (fig. 1). This site was selected because electric current was available to operate the recording devices at a previously established streamflow-gaging station on the Canadian River, and the site easily could be accessed throughout the year. Because of the generally uniform climate in North Park, air-temperature data and solar-radiation data readily could be transferred to the study basins for modeling purposes. Any missing air-temperature data, including data for July to October 1979, was completed with air-temperature data from the National Weather Service field station in Walden.

Solar-radiation data also were obtained at the meteorological station (fig. 1). In addition, PRMS provides the capability to compute solar radiation if these data are not available or to complete missing periods of data. This computation can be done by one of two user-selected methods (Leavesley and others, 1983, p. 15-17); the degree-day method was used for this study. Both methods require daily maximum and minimum air-temperature data to estimate solar radiation.

Watershed Partitioning

Williams Draw basin was partitioned into six HRU's (fig. 6, table 2), primarily on the basis of slope and aspect. Variations in other physical characteristics, such as quantity of precipitation, elevation, type of soil, and type of vegetation cover are not very pronounced.

Slope and aspect in the basin are important factors with respect to snow accumulation and melting. Frequent windy conditions during winter result in considerable movement of snow in the hilly shrub and grass environment of Williams Draw. Wind direction generally is from the south-southwest; the same windward aspects consistently are subjected to snow removal, and the same leeward aspects consistently are subjected to snow deposition throughout the winter. The slope and aspect of a particular area have a considerable effect on the quantity of snow removal and deposition. In addition, slope and aspect also affect the quantity of solar radiation received on a surface and, thus, affect the rate of snowmelt and sublimation.

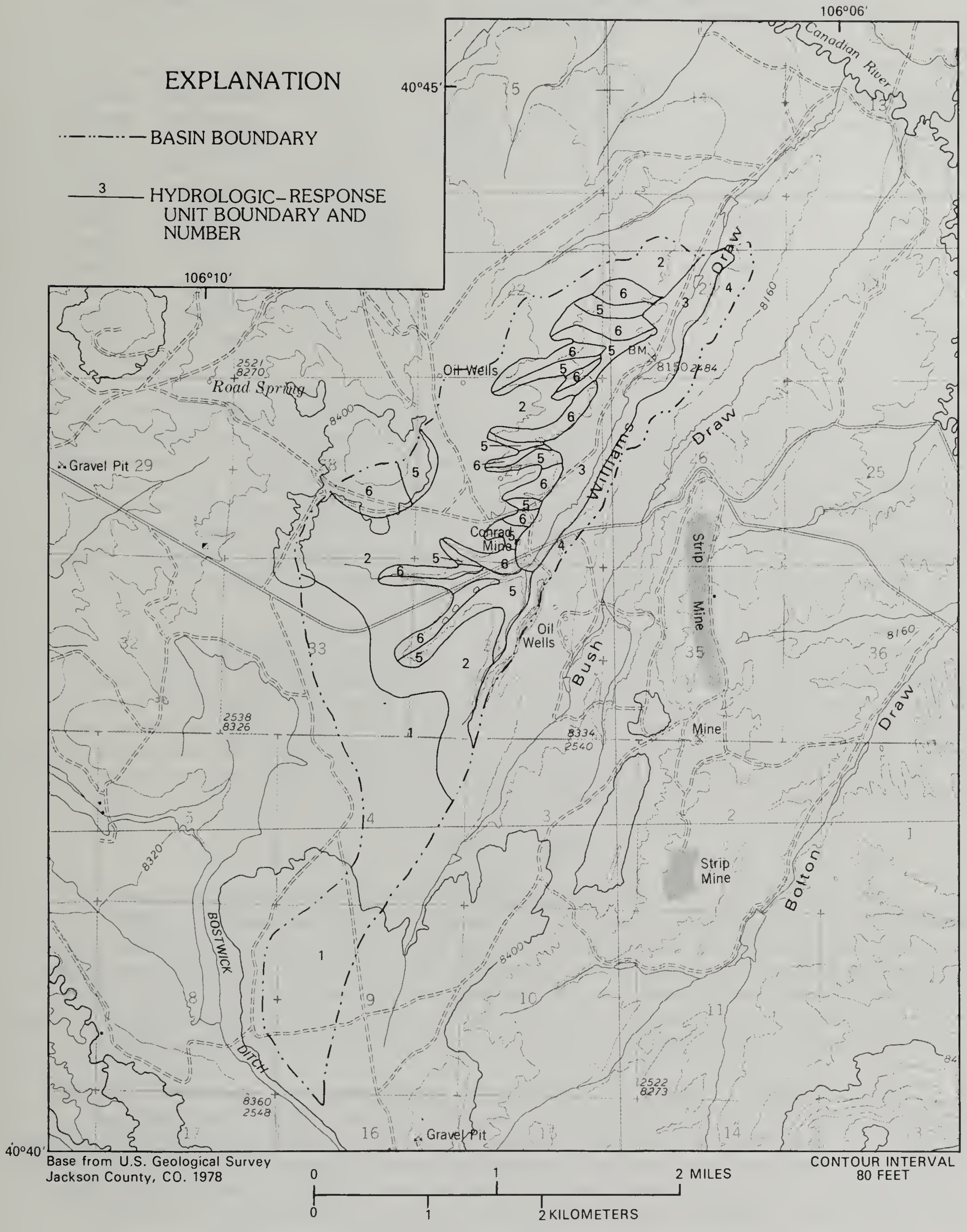

Figure 6.--Hydrologic-response units for Williams Draw basin.

Table 2.--*Selected characteristics of hydrologic-response units for Williams Draw basin*

Hydrologic-response unit (fig. 6)	Area (percent of total)	Median elevation (feet)	Average slope (percent)	Major aspect	Dominant type of vegetation	Primary type of soil
1	27.3	8,405	1	Northeast	Shrub	Loam
2	34.2	8,345	5	East	Shrub	Loam
3	11.1	8,185	6	Northeast	Shrub	Loam
4	7.1	8,250	11	Northwest	Grass	Loam
5	10.2	8,260	15	Northwest	Shrub	Loam
6	10.1	8,260	13	Southeast	Grass	Loam

During the first winter (1979-80) of data collection, snowfall was substantial in the basin, and the pattern of snow accumulation and redistribution was observed by onsite visits. Snow courses were established in areas with obviously different snowpack accumulation; these observations and measurements of snowpack accumulation became the primary basis of HRU delineation for Williams Draw basin. Because of the small size of the basin and the uniformity of soil, only one soil-zone reservoir, one subsurface reservoir, and one ground-water reservoir were defined for Williams Draw basin.

Bush Draw basin was partitioned into nine HRU's (fig. 7, table 3), also primarily on the basis of slope and aspect. However, snowpack water-equivalent data were not available to help define the pattern of snowpack accumulation and redistribution. The delineation of HRU's for Bush Draw basin (fig. 7) is not as detailed as the delineation for Williams Draw basin (fig. 5), largely because the drainage network in Bush Draw is not as extensive as it is in Williams Draw. One soil-zone, one subsurface, and one ground-water reservoir also were defined for Bush Draw basin.

Model Parameters

Simulation of the various components of a watershed system by any hydrologic model requires the definition of numerous model parameters. PRMS requires user-supplied values for about 40 to 45 parameters for simulation of daily streamflow that results from snowmelt and rainfall. Brief descriptions of the model parameters used in the present study are listed in table 9 ("Supplemental Information" section at the back of this report.) More detailed descriptions of the parameters are given in Leavesley and others (1983).

For this study, values for PRMS model parameters were obtained from the following sources: (1) topographic maps and soil and vegetation surveys previously described herein; (2) meteorological data obtained as a part of the study; (3) other ongoing studies in northwestern Colorado that also used PRMS (J.M. Norris, U.S. Geological Survey, oral commun., 1984); and (4) techniques and references presented in the PRMS user's manual (Leavesley and others, 1983).

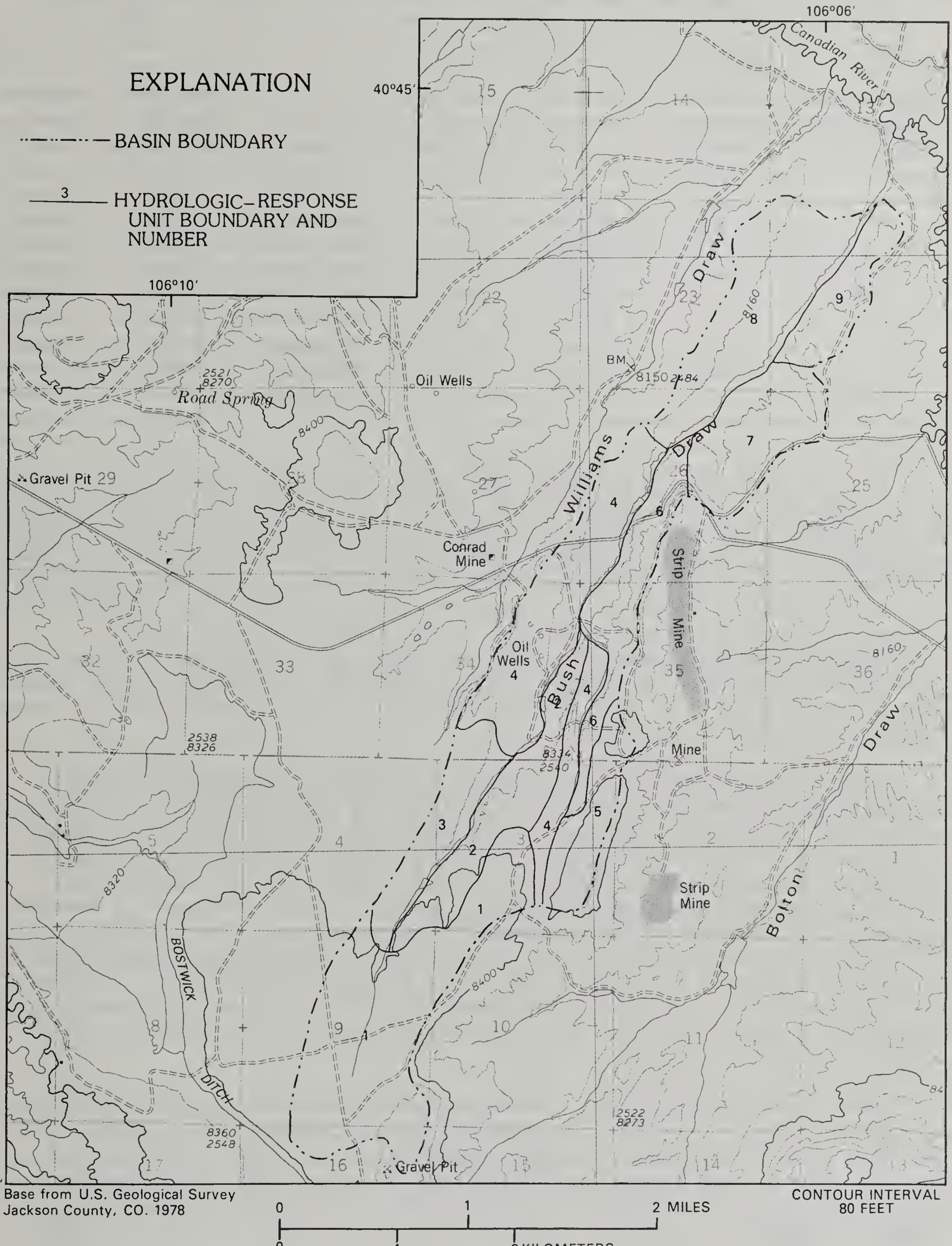

Figure 7.--Hydrologic-response units for Bush Draw basin.

Table 3.--*Selected characteristics of hydrologic-response units for Bush Draw basin*

Hydrologic response unit (fig. 7)	Area (percent of total)	Median elevation (feet)	Average slope (percent)	Major aspect	Dominant type of vegetation	Primary type of soil
1	22.4	8,440	1	Northeast	Shrub	Loam
2	9.1	8,310	11	Northwest	Shrub	Loam
3	7.1	8,330	10	Southeast	Shrub	Loam
4	17.3	8,265	7	Southeast	Shrub	Loam
5	5.6	8,415	8	Northwest	Grass	Loam
6	8.5	8,260	15	Northwest	Grass	Loam
7	9.5	8,205	7	Northwest	Shrub	Loam
8	14.6	8,150	4	Southeast	Shrub	Loam
9	5.9	8,155	10	Northwest	Grass	Loam

Four of the model parameters, BST, SMAX, TRNCF, and DSCOR were selected to be optimized in calibration of the model. These four parameters and the methods used to estimate their initial values are described in the following paragraphs. BST, SMAX, and TRNCF were selected for calibration because they were found to be statistically sensitive in predicting streamflow (Leavesley and others, 1981). DSCOR was included because it provided the capability to account for snow-catch deficiency and redistribution of snow by wind. Although other model parameters also were found to be important in predicting streamflow (Leavesley and others, 1981), hydrologic conditions in the study area and availability of data did not warrant the use of additional parameters for calibration of the model.

BST, a nondistributed parameter, is the base air temperature used to determine the form (rain, snow, or a mixture) of precipitation. If the daily maximum air temperature is greater than BST, then precipitation is assumed to be all rain. If the daily minimum air temperature is less than or equal to BST, then precipitation is assumed to be all snow. For air-temperature conditions in between those described, a mixture of rain or snow is assumed; the method of computation is described in Leavesley and others (1983, p. 13-14). Depending on the units of the input air-temperature data, BST may be either in degrees Fahrenheit (°F) or in degrees Celsius (°C). A value of 32 °F was selected as an initial estimate for BST on the basis of about 2,400 simultaneous observations of the form of precipitation and values of air temperature (U.S. Army, 1956, p. 55).

SMAX, distributed by HRU, is the maximum available water-holding capacity of the soil zone, in inches. No information was available to determine if or how SMAX should vary among the HRU's, so an initial value of 9.0 in. was used for all HRU's. This initial value was used in other studies in northwestern Colorado that also used PRMS (J.M. Norris, U.S. Geological Survey, oral commun., 1984).

TRNCF is the transmission coefficient for the vegetation canopy over the snowpack; TRNCF is distributed by HRU. Initial values for TRNCF were estimated from the relation between winter vegetation-cover density and values of TRNCF presented in Leavesley and others (1983, p. 44). Although the relation presented was for species of pine and fir, use of the relation to approximate initial values of TRNCF for other types of vegetation has been satisfactory (J.M. Norris, U.S. Geological Survey, oral commun., 1984). The initial values for TRNCF ranged from 0.55 to 0.75.

DSCOR is the daily precipitation correction factor for snow; a DSCOR value is assigned for each HRU. Initial values for DSCOR were estimated on the basis of measurements of snowpack water equivalent made in Williams Draw basin during the winter 1979-80. Snowpack water equivalent in the different HRU's was measured once or twice during the winter and again during the first week of April when the snowpack water equivalent generally was at a maximum. Values for DSCOR were estimated from the ratio of the snowpack water equivalent measured on each HRU on April 6, 1980, to the total recorded precipitation from November 1, 1979, to April 6, 1980. During that period, recorded precipitation was 4.35 in., whereas the snowpack water equivalent measured on April 6 ranged from about 2.2 in. on HRU's 4 and 6 to about 8.6 in. on HRU 5. Thus, initial values for DSCOR ranged from about 0.5 to 2.0. Initial estimated values for the model parameters, BST, SMAX, TRNCF, and DSCOR are listed in table 4. Values for all model parameters used in the present study are listed in table 9 in the "Supplemental Information" section at the back of this report.

Table 4.--*Initial and optimized values for selected model parameters for Williams Draw basin*

[BST, base air temperature used to determine the form or a mixture of precipitation form (rain, snow), in degrees Fahrenheit; SMAX, maximum available water-holding capacity of the soil zone, in inches; TRNCF, transmission coefficient for the vegetation canopy over the snowpack, expressed as a decimal fraction; DSCOR, daily precipitation correction factor for snow, expressed as a decimal fraction]

Parameter	Hydrologic-response unit					
	1	2	3	4	5	6
			Initial Value			
BST	32.0 (not distributed)					
SMAX	9.00	9.00	9.00	9.00	9.00	9.00
TRNCF	.65	.65	.55	.55	.75	.55
DSCOR	1.45	1.45	1.05	0.50	2.00	0.50
			Optimized value			
BST	44.8					
SMAX	6.65	6.65	6.65	6.65	6.65	6.65
TRNCF	.80	.78	.80	.60	.80	.59
DSCOR	1.75	1.75	1.55	1.00	2.10	1.20

Calibration

Calibration was done by manually adjusting (optimizing) the parameters according to the following steps: (1) Repeated model simulations with coarse adjustment of BST, TRNCF, and DSCOR were done until the simulated snowpack water equivalent on each HRU on April 6, 1980, approximated the measured snowpack water equivalent on that day; (2) coarse adjustments of SMAX were done to achieve a simulated streamflow volume similar to the recorded streamflow volume; and (3) numerous additional simulations with smaller adjustments of BST, SMAX, TRNCF, and DSCOR were done to improve the timing of simulated snowmelt and simulated peak daily streamflow while still maintaining the correct quantity of simulated snowpack water equivalent and simulated streamflow volume. Optimized values for BST, SMAX, TRNCF, and DSCOR are listed in table 4.

Calibration was a repetitive procedure of adjusting one or more of the four parameters (BST, SMAX, TRNCF, and DSCOR) to achieve a simulated streamflow hydrograph that compared reasonably well, both quantitatively and qualitatively, with the recorded streamflow hydrograph. The calibration procedure used in this study assumed that any errors in other model parameters would be accounted for in the optimized values for BST, SMAX, TRNCF, and DSCOR. This may, in part, account for some of the differences between the initial and the optimized values of the parameters.

The optimized value for BST, 44.8 °F (table 4) is considerably larger than the value determined for BST in other studies that also used PRMS. For example, Cary (1984, p. 41) reported optimized values for BST between 31.1 °F and 38.3 °F, and Norris and Parker (1985, p. 24) reported a value of 34.0 °F. The somewhat large value of 44.8 °F for BST partly may be the result of errors in other model parameters or partly may be caused by weather conditions, which at times are highly variable in the study area during a single 24-hour period. These changing weather conditions, which affect the form of precipitation, may not adequately be represented, at times, in PRMS subroutines using only daily maximum and minimum air temperatures. Regardless, the optimized value of BST is somewhat anomalous and should not be considered as a value readily transferred to other areas.

The optimized value for SMAX (table 4) decreased considerably from the initial value. Changes in the value of SMAX in the calibration can be attributed to: (1) error in the initial value; (2) a response to changes in the other three calibration parameters; and (3) errors in other model parameters.

Optimization of TRNCF and DSCOR was interrelated, so the two will be discussed together. TRNCF generally was increased during calibration to provide earlier simulated snowmelt and larger simulated daily streamflow, corresponding more closely to recorded snowmelt streamflow. Increases in the value of TRNCF also resulted in decreased simulated snowpack water equivalent because of increased melting of snow during the snowpack accumulation period. The value of DSCOR then was increased to compensate for the decrease in snowpack water equivalent on each HRU.

Simulated and recorded streamflow volumes for Williams Draw for the 1980 and 1981 runoff periods are summarized in table 5. The largest differences between simulated and recorded streamflow volumes occurred between April and May 1980. These differences may be explained, in part, by runoff over frozen soil during snowmelt in April 1980, even though extensive conditions of frozen soil in Williams Draw basin were not positively ascertained during April 1980. The following discussion pertaining to differences between simulated and recorded streamflow volume during 1980, however, implies that runoff over frozen soil may have existed because: (1) Frozen soils are common in North Park during most winters and the frozen soils usually persist throughout the winter; (2) the winter of 1979-80 was colder than normal, and the very cold temperatures during November and December 1979, together with the absence of any substantial snowpack until late December, undoubtedly enabled formation of frozen soils to a considerable depth; (3) the depth of accumulated snowpack only averaged 1 to 2 ft, and continued cold temperatures into mid-April probably prevented complete thawing of the frozen soils; and (4) studies of runoff from reclaimed mine spoils adjacent to the study area during April 1980 also indicated the possibility of runoff over frozen soils (B.P. Van Haveren, U.S. Bureau of Land Management, oral commun., 1984).

Table 5.--*Summary of simulated and recorded streamflow volumes at station 06619420 Williams Draw near Walden, 1980-81*

[--, not applicable]

Streamflow period	Streamflow (acre-feet) Simulated[1]	Streamflow (acre-feet) Recorded	Absolute error (acre-feet) Simulated-recorded	Relative error (percent) $\frac{\text{Simulated-recorded}}{\text{recorded}} \times 100$
		1980		
April	85.3	98.5	-13.2	-13.4
May	35.7	23.8	11.9	50.0
June	1.05	.42	.63	150
Total for runoff period	123	123	0	0
		1981		
Total for runoff period	4.26	0	4.26	--

[1]Sums of monthly streamflows are not necessarily equal to the total for the runoff period because small volumes of streamflow were simulated for some of the months not listed.

Because PRMS has no capability to account for frozen soil, the model was "infiltrating" snowmelt into the subsurface to satisfy the soil-moisture storage capacity of the soil profile during late April. In actuality, some of this snowmelt probably produced runoff because the frozen soil conditions

decreased infiltration. Thus, simulated streamflow volume was smaller than recorded streamflow volume. Simulated streamflow volume during May 1980, however, is larger than recorded streamflow volume (table 5). This also may, in part, be the result of the frozen soil conditions in April because the increased quantity of simulated infiltration during April may have provided wetter antecedent soil-moisture conditions for precipitation in early May, resulting in the larger simulated streamflow volume.

The differences between the April and May 1980 simulated and recorded streamflow volumes tend to offset, so the simulated and recorded streamflow volumes for the 1980 runoff period are the same (table 5). Although the simulated volume of streamflow for the 1981 runoff period seems large in comparison to zero recorded streamflow, the overall error for the entire calibration period is not substantial.

The qualitative comparison of simulated and recorded streamflow for the 1980 runoff period is presented by the hydrographs in figure 8. Hydrographs for the 1981 runoff period are not shown because only a few days had simulated streamflow, and this flow was small (maximum daily simulated streamflow was 0.5 ft^3/s). Simulated streamflow resulting from snowmelt generally lagged recorded streamflow by 2 to 5 days. During April, runoff over frozen soil may be part of the reason recorded streamflow preceded simulated streamflow. Differences between simulated and recorded streamflow, both with respect to volume and timing, also are caused by parameter errors and the inability to completely describe the hydrologic processes of a natural watershed by use of a mathematical model (PRMS).

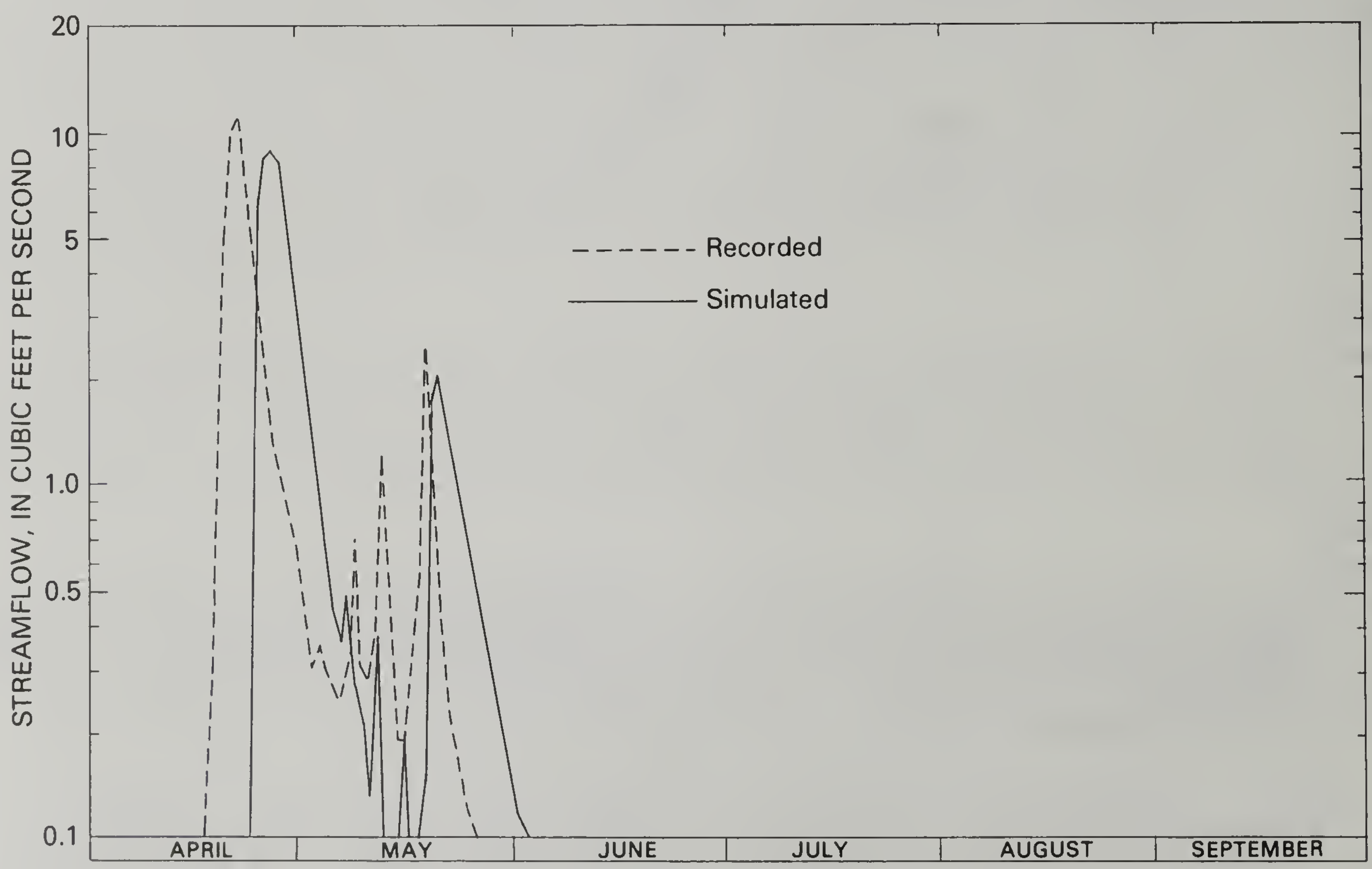

Figure 8.--Simulated and recorded streamflow at station 06619420 Williams Draw near Walden, 1980.

Verification

Calibration of PRMS was verified by simulation of streamflow for April through September, 1982 and 1983, and by comparing the results to recorded streamflow from the same period. Values for all model parameters were held constant for the verification simulation.

Simulated and recorded streamflow volumes for the verification period are summarized in table 6. The total volumes of simulated streamflow that result primarily from snowmelt (April and May, 1982 and 1983) compare quite well with recorded streamflow volumes during those 2 months (table 6). The total simulated and recorded streamflow volumes for the runoff periods are not as comparable; therefore, most of the error in the total simulated streamflow volume is attributable to the summer months when streamflow results from rainfall.

Near zero streamflow resulting from rainfall was recorded during the calibration period (1980 and 1981), but considerable streamflow resulting from rainfall was recorded during 1983. Since there was no opportunity to optimize model parameters that relate to rainfall runoff, errors in simulating rainfall runoff could result. This does not necessarily imply that the differences between simulated and recorded streamflow volumes during the summers of 1982

Table 6.--*Summary of simulated and recorded streamflow volumes at station 06619420 Williams Draw near Walden, 1982-83*

[--, not applicable]

Streamflow period	Streamflow (acre-feet) Simulated[1]	Streamflow (acre-feet) Recorded	Absolute error (acre-feet) Simulated-recorded	Relative error (percent) $\frac{\text{Simulated-recorded}}{\text{recorded}} \times 100$
			1982	
April	3.85	2.40	1.45	60.4
May	1.25	2.14	-.89	-41.6
July	.77	0	.77	--
September	1.69	.22	1.47	668
Total for runoff period	8.71	4.76	3.95	83.0
			1983	
April	61.6	54.2	7.4	13.6
May	31.8	39.6	-7.8	-19.7
June	1.69	3.03	-1.34	-44.2
July	4.56	6.47	-1.91	-29.5
August	2.46	9.10	-6.64	-73.0
Total for runoff period	102	112	-10	-8.93

[1]Sums of monthly streamflows are not necessarily equal to the total for the runoff period because small volumes of streamflow were simulated for some of the months not listed.

and 1983 would have been less had there been more opportunity to optimize rainfall-runoff parameters.

A qualitative comparison of simulated and recorded streamflow for the verification simulations is shown in figure 9. The simulated snowmelt peak in April 1982 also lags the recorded peak, but in April 1983 timing and magnitude of simulated and recorded streamflow resulting from snowmelt shows little difference. The general lack of agreement between simulated and recorded streamflow resulting from rainfall also is evident in figure 9.

Sensitivity Analysis

In order to determine how the parameters, BST, SMAX, TRNCF, and DSCOR, contributed to modeling errors, sensitivity of the modeling results to changes in these parameters was analyzed. This analysis was completed using the sensitivity analysis capability of PRMS (Leavesley and others, 1983, p. 57-60). Both the calibration and the verification periods were used in the sensitivity analysis.

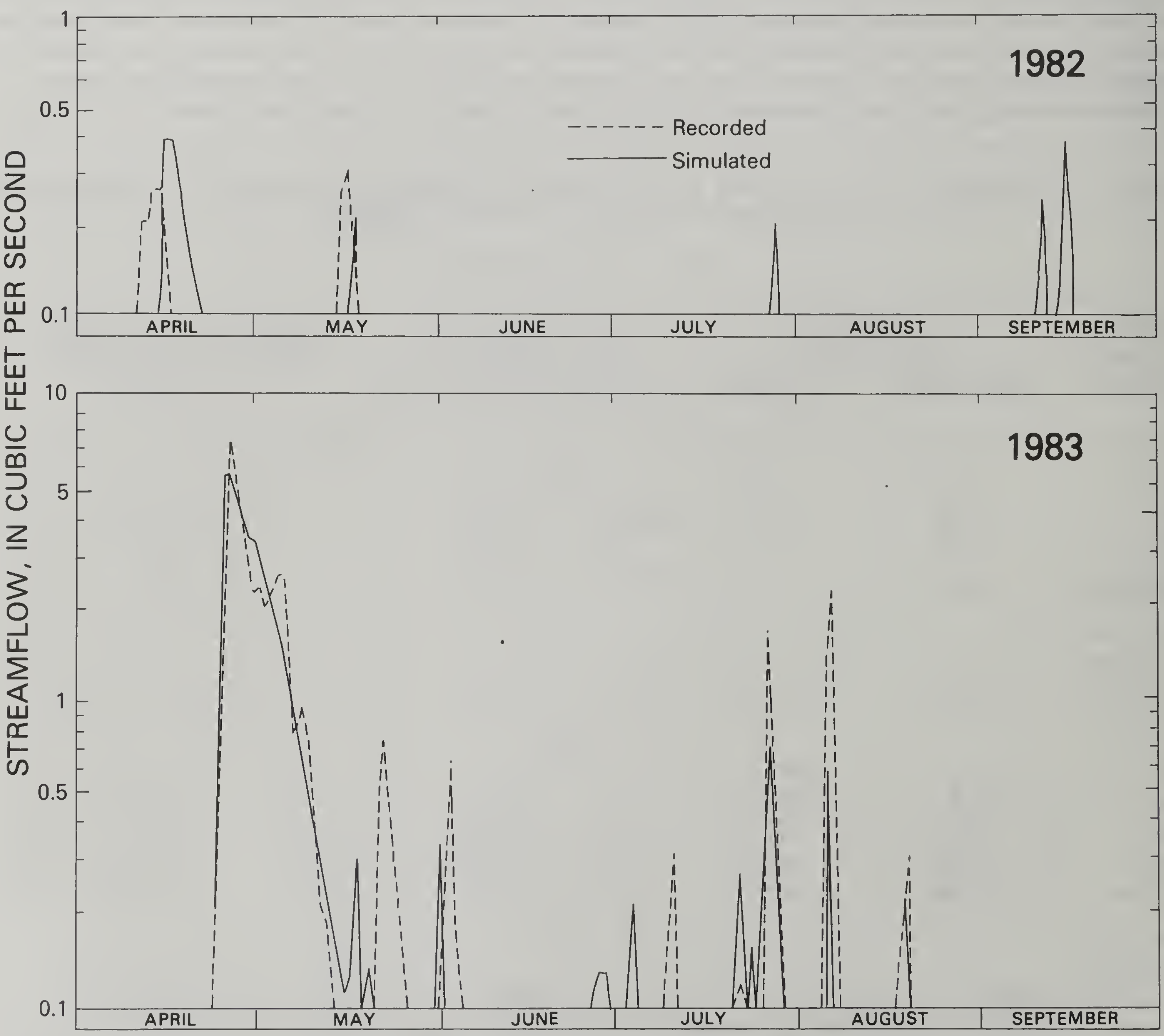

Figure 9.--Simulated and recorded streamflow at station 06619420 Williams Draw near Walden, 1982-83.

Results of the sensitivity analysis are shown in figure 10, which shows the percentage increase in the average squared prediction error (Leavesley and others, 1983, p. 56, 58) for changes in the optimized parameters of 10 percent or less. BST shows the largest sensitivity, followed by SMAX, DSCOR, and TRNCF. Even a 10 percent change in TRNCF would result in a 60 percent increase in the average squared prediction error.

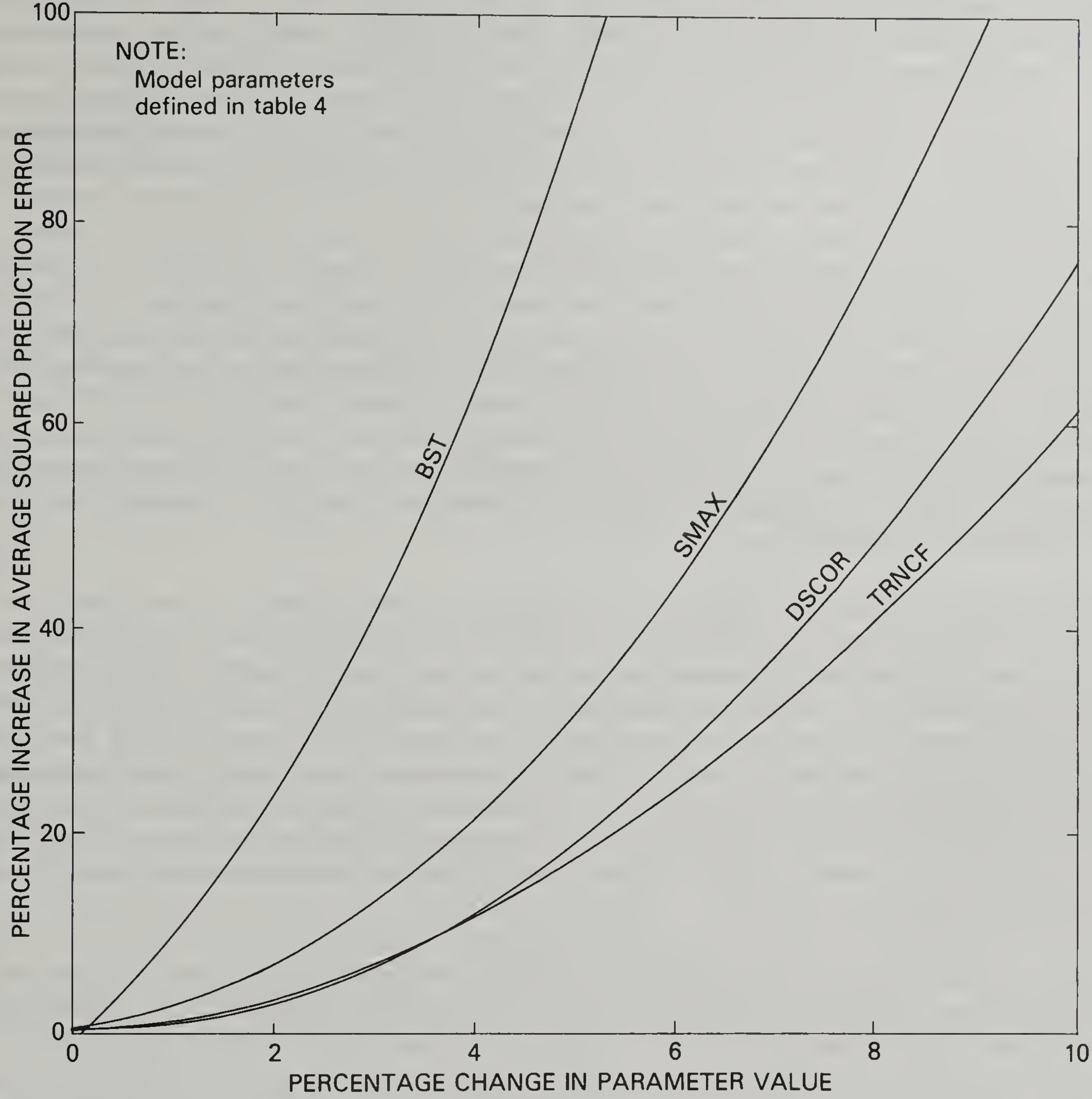

Figure 10.--Sensitivity of average squared prediction error to optimized model parameters for simulated runoff, 1980-84.

These four parameters were sensitive because: (1) BST, TRNCF, and DSCOR affect the "accumulation" of snowpack in the model simulations; (2) TRNCF affects the rate and timing of simulated snowmelt; (3) SMAX affects the volume of simulated streamflow; and (4) nearly all recorded streamflow in Williams Draw basin resulted from snowmelt.

Transferability of Calibrated Model

One of the objectives of the development of PRMS was to provide some capability to reasonably estimate hydrologic responses of basins in coal areas

for which little or no hydrologic information is available. In the vicinity of Williams Draw, as well as in other areas of North Park, other small ephemeral stream basins could be subjected to coal-resource development at some time in the future. No hydrologic information currently is available for most of these basins.

Application of the model to these other basins would require estimation of all model parameters, including BST, SMAX, TRNCF, and DSCOR. Parameters relating to the physical characteristics of the basin, such as slope, aspect, type of soil, and type of vegetation, could be estimated reasonably from available data as they were for Williams Draw basin. The model parameters relating to climatic characteristics which were estimated for Williams Draw basin probably could be transferred to other locations because of the generally uniform climate and elevation throughout the North Park area. Although the calibrated value (44.8 °F) for BST, also a climatic parameter, is somewhat anomalous, transferability of that value within North Park is assumed valid for purposes of the following discussion. Estimated values for other model parameters, such as those relating to the subsurface and ground-water reservoirs, also are assumed to be transferable provided that the other basins are somewhat hydrologically and geologically similar to Williams Draw basin. The primary focus, then, in transferring PRMS to another basin in the North Park area would be in properly estimating values for SMAX, TRNCF, and DSCOR for each HRU defined for that basin.

Individual values of TRNCF and DSCOR were required for each HRU defined for Williams Draw basin to provide a simulated snowpack water equivalent which was comparable to measured snowpack water equivalent. Slope and aspect are important factors in the accumulation (redistribution) of snow; therefore, because the slopes and aspects for HRU's defined for other basins undoubtedly will be different from those within Williams Draw, the pattern of snowpack accumulation also will be different. Thus, different values of TRNCF and DSCOR probably would be required for other basins. The values of SMAX for other basins may or may not be different from the value determined for the Williams Draw basin.

Data to properly estimate SMAX, TRNCF, and DSCOR may not be available for application of PRMS to other basins in the North Park area. Therefore, a test was done to determine if the values determined for those parameters in the present study could be used in other applications of the model in this area. For this test, average basin values of SMAX, TRNCF, and DSCOR were determined by weighting the individual HRU values that were optimized during calibration of the model for Williams Draw basin. SMAX (6.65 in.) was identical on all HRU's; therefore, the weighted value for this parameter also was 6.65 in.; weighted average values were 0.76 for TRNCF and 1.65 for DSCOR.

The model then was reapplied to Williams Draw basin by using the single weighted value of SMAX, TRNCF, and DSCOR on each HRU, while keeping all other parameters the same as in the calibration and verification simulations. Results of the test simulation are summarized in table 7. Comparison of the results to tables 5 and 6 indicates that simulated streamflow volumes for the test are substantially less than the streamflow volumes for the calibration and verification simulations, especially during snowmelt periods.

Use of the weighted values for SMAX, TRNCF, and DSCOR was tested further by application of PRMS to Bush Draw basin, located adjacent to Williams Draw basin. Streamflow records were obtained for Bush Draw for the 1981-83 runoff periods to provide additional data for the application of the model in this area; no other data were obtained. Model parameters for the basin that were based on physical characteristics, such as slope, aspect, type of soil, and type of vegetation (table 3) were estimated from the same sources and in the same manner as was done for Williams Draw basin. The remaining model parameters used were identical to those used for Williams Draw basin, including the previously determined weighted values of SMAX, TRNCF, and DSCOR. Results of the test application of PRMS to Bush Draw basin are summarized in table 8, which also indicates that simulated streamflow volumes resulting from snowmelt are considerably less than recorded streamflow volumes.

Results of the test simulations on Williams Draw (table 7) and on Bush Draw (table 8), using single weighted values for SMAX, TRNCF, and DSCOR, indicate that simulated streamflow volumes are much smaller than recorded streamflow volumes for years that had substantial snowpack accumulation (1980 and 1983). Because the weighted values of SMAX were the same as the nonweighted values, and because values for all other model parameters basically were the same as in the calibration and verification simulations, the difference between simulated and recorded snowmelt streamflow volumes in the two test simulations largely can be attributed to the use of weighted values of TRNCF and DSCOR.

Individual values of TRNCF and DSCOR for each HRU were used in the calibration to provide a pattern of simulated snowpack accumulation that was similar to the pattern of measured snowpack accumulation. The weighted values for TRNCF and DSCOR provided a simulated pattern of snowpack accumulation different from that which was measured, resulting in simulated streamflow volume much less than recorded streamflow volume. Calibration of PRMS to Williams Draw basin, therefore, largely was successful because of the availability of snowpack water-equivalent data; these data facilitated the determination of optimimum values of TRNCF and DSCOR. Availability of these data, which can be used to help determine the values for TRNCF and DSCOR, then, will be a limiting factor in the successful transferability of the model in the vicinity of Williams Draw basin.

SUMMARY

The precipitation-runoff modeling system was applied to two small basins in Jackson County, Colorado. The model first was calibrated by using daily streamflow data for Williams Draw basin for April through September, 1980 and 1981. The calibration was verified by using daily streamflow data for April through September, 1982 and 1983. The transferability of the model was tested by application to Bush Draw basin, using daily streamflow data for April through September, 1981 through 1983.

Both basins were divided into similar hydrologic-response units, primarily on the basis of slope and aspect, which are important in the accumulation of snow and its redistribution by wind. Snowpack water-equivalent data for Williams Draw basin were used to help define the hydrologic-response units; however, these data were not available for Bush Draw basin.

Table 7.--*Summary of simulated and recorded streamflow volumes at station 06619420 Williams Draw near Walden, 1980-83, using the same weighted value for SMAX, TRNCF, and DSCOR on each hydrologic-response unit*

[SMAX, maximum available water-holding capacity of the soil zone, in inches; TRNCF, transmission coefficient for the vegetation canopy over the snowpack, expressed as a decimal fraction; DSCOR, daily precipitation correction factor for snow, expressed as a decimal fraction; --, not applicable]

Streamflow period	Streamflow (acre-feet) Simulated[1]	Streamflow (acre-feet) Recorded	Absolute error (acre-feet) Simulated-recorded	Relative error (percent) (Simulated-recorded / recorded) × 100
		1980		
April	7.66	98.5	-90.8	-92.2
May	18.5	23.8	-5.3	-22.3
June	.97	.42	.55	131
Total for runoff period	28.0	123	-95.0	-77.2
		1981		
Total for runoff period	4.28	0	4.28	--
		1982		
Total for runoff period	4.96	4.76	0.20	4.20
		1983		
April	16.7	54.2	-37.5	-69.2
May	7.56	39.6	-32.0	-80.9
June	1.67	3.03	-1.36	-44.9
July	4.56	6.47	-1.91	-29.5
August	2.46	9.10	-6.64	-73.0
Total for runoff period	33.3	112	-78.7	-70.3

[1]Sums of monthly streamflows are not necessarily equal to the total for the runoff period because small volumes of streamflow were simulated for some of the months not listed.

Table 8.--*Summary of simulated and recorded streamflow volumes at station 06619415 Bush Draw near Walden, 1981-83, using the same weighted value for SMAX, TRNCF, and DSCOR on each hydrologic-response unit*

[SMAX, maximum available water-holding capacity of the soil zone, in inches; TRNCF, transmission coefficient for the vegetation canopy over the snowpack, expressed as a decimal fraction; DSCOR, daily precipitation correction factor for snow, expressed as a decimal fraction; --, not applicable]

Streamflow period	Streamflow (acre-feet) Simulated[1]	Streamflow (acre-feet) Recorded	Absolute error (acre-feet) Simulated-recorded	Relative error (percent) $\frac{\text{Simulated-recorded}}{\text{recorded}} \times 100$
		1981		
Total for runoff period	6.03	0.06	5.97	9,950
		1982		
Total for runoff period	5.89	0	5.89	--
		1983		
April	16.1	27.6	-11.5	-41.7
May	4.32	24.2	-19.9	-82.2
June	1.75	.02	1.73	8,650
July	4.76	12.7	-7.94	-62.5
August	2.56	4.36	-1.80	-41.3
Total for runoff period	30.4	68.9	-38.5	-55.9

[1]Sums of monthly streamflows are not necessarily equal to the total for the runoff period because small volumes of streamflow were simulated for some of the months not listed.

Four model parameters, BST, SMAX, TRNCF, and DSCOR were selected to be optimized during the calibration. BST is the base air temperature used to determine the form (rain, snow, or a mixture) of precipitation; SMAX is the maximum available water-holding capacity of the soil zone; TRNCF is the transmission coefficient for the vegetation canopy over the snowpack; and DSCOR is the daily precipitation correction factor for snow. BST, TRNCF, and DSCOR primarily are important in simulation of snowpack accumulation and timing of snowmelt, whereas SMAX primarily is important in simulated streamflow volume. Because most streamflow results from snowmelt, model parameters that relate to snowpack accumulation and melting were most important in calibration of the model.

For the calibration and verification, simulated streamflow volumes compared closely to recorded streamflow volume during years with substantial snowpack accumulation (1980 and 1983). However, during years with little or no snowpack accumulation (1981 and 1982), simulated streamflow volume did not compare closely to recorded streamflow volume. Simulated streamflow resulting from snowmelt lagged recorded streamflow by 2 to 5 days during 1980 and 1982, but during 1983 timing of simulated streamflow was nearly identical to recorded streamflow. During 1980, the possibility of runoff over frozen soil could partly explain the differences between simulated and recorded streamflow. Because little runoff resulted from rainfall during 1980 and 1981, model parameters that relate to rainfall runoff could not be optimized.

Transferability of the model was tested by using weighted values of the four optimized parameters; however, because BST was not distributed, no weighted value was determined. The optimization of TRNCF and DSCOR was possible because snowpack water-equivalent data were available for Williams Draw basin. These data were not available for Bush Draw basin; thus values for TRNCF and DSCOR for each hydrologic-response unit could not be reasonably estimated.

By use of the weighted values for the optimized parameters, the precipitation-runoff modeling system first was reapplied to Williams Draw basin for the four calibration and verification periods. Simulated total streamflow volumes during the 1980 and 1983 runoff periods were substantially less than in the original calibration and verification simulations. The model then was applied to Bush Draw basin, also by using weighted values for SMAX, TRNCF, and DSCOR. Simulated total streamflow volumes also did not compare closely to recorded total streamflow volumes.

The inadequate results of the streamflow simulations by use of the weighted model parameters indicated that without snowpack water-equivalent data, transferability of the precipitation-runoff modeling system near the study area would not be very reliable. The snowpack data would be necessary to adequately estimate DSCOR, which was used in the model to account for the spatial variability in snowpack accumulation and redistribution of snow by wind.

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SUPPLEMENTAL INFORMATION

Table 9.--*Precipitation-runoff modeling system parameters for the daily simulation mode*

[Parameter definitions modified from Leavesley and others (1983); °F., degrees Fahrenheit; °C., degrees Celsius; HRU, hydrologic response unit]

Pararmeter	Definition
AJMX	Rain and snow mixture adjustment coefficient
BST	Temperature below which precipitation is snow and above which it is rain (°F or °C)
COVDNS	Summer cover density for major vegetation for each HRU (decimal percent)
COVDNW	Winter cover density for major vegetation for each HRU (decimal percent)
CTS	Air temperature coefficient for computation of evapotranspiration for months 1-12
CTW	Coefficient for computing snowpack sublimation from potential evapotranspiration
CTX	Air temperature coefficient for computation of evapotranspiration for each HRU
DENI	Initial density of new-fallen snow (decimal percent)
DENMX	Average maximum density of snow pack (decimal percent)
DSCOR	Daily precipitation correction factor for snow for each HRU
EAIR	Emissivity of air on days without precipitation
FWCAP	Free water holding capacity of snowpack (decimal percent of snowpack water equivalent)
GSNK	Coefficient to compute seepage from each ground-water reservoir to a ground-water sink
PARS	Correction factor for computed solar radiation on summer day with precipitation (decimal percent)
PARW	Correction factor for computed solar radiation on winter day with precipitation (decimal percent)
PAT	Maximum air temperature, which when exceeded, forces precipitation to be all rain
RCB	Routing coefficient for each ground-water reservoir

Table 9.--*Precipitation-runoff modeling system parameters for the daily simulation mode*--continued

Pararmeter	Definition
RCF	Linear routing coefficient for each subsurface reservoir
RCP	Nonlinear routing coefficient for each subsurface reservoir
RDC	Intercept of maximum air-temperature and degree-day function (°C or °F)
RDM	Slope of maximum air-temperature and degree-day function
RDMX	Maximum percent of potential solar radiation (decimal)
RECHR	Storage in upper part of soil profile where losses occur as evaporation and transpiration (inches)
REMX	Maximum value of RECHR for each HRU (inches)
RES	Storage in each subsurface reservoir (acre-inches)
RESMX	Seepage coefficient from subsurface reservoir to ground-water reservoir
REXP	Exponent of seepage function for seepage from subsurface reservoir to ground-water reservoir
RMXA	Proportion of rain in rain and snow event above which snow albedo is not reset for snowpack accumulation stage
RMXM	Proportion of rain in rain and snow event above which snow albedo is not reset for snowpack melt stage
RNSTS	Interception storage capacity of unit area of vegetation for rain during summer period, for each HRU (inches)
RNSTW	Interception storage capacity of unit area of vegetation for rain during winter period for each HRU (inches)
RSEP	Seepage rate from each subsurface reservoir to ground-water reservoir (inches per day)
SCN	Minimum possible contributing area of HRU (decimal fraction)
SCX	Maximum possible contributing area of HRU (decimal fraction)
SC1	Coefficient in surface runoff contributing area and soil-moisture index relation

Table 9.--*Precipitation-runoff modeling system parameters for the daily simulation mode*--continued

Pararmeter	Definition
SEP	Seepage rate from soil moisture excess to each ground-water reservoir (inches per day)
SETCON	Snowpack settlement time constant
SMAX	Maximum available water holding capacity of soil profile for each HRU (inches)
SNST	Interception storage capacity of vegetation for snow, for each HRU (inches, water equivalent)
SRX	Maximum daily snowmelt infiltration capacity of soil profile at field capacity for each HRU (inches)
TLN	Lapse rate for minimum daily temperature for months 1-12 (°C or °F)
TLX	Lapse rate for maximum daily air temperature for months 1-12 (°C or °F)
TNAJ	Adjustment for minimum air temperature for slope and aspect for each HRU (°C or °F)
TRNCF	Transmission coefficient for shortwave radiation through vegetation canopy for each HRU
TXAJ	Adjustment for maximum air temperature for slope and aspect for each HRU (°C or °F)

Table 10.--*Values for model parameters used in application of precipitation-runoff modeling system to Williams Draw and Bush Draw basins*

[Parameters defined in table 9; dashes indicate not applicable; °C, degrees Celsius]

Parameter	Units	Value of parameter for indicated month											
		January	February	March	April	May	June	July	August	September	October	November	December
AJMX	---	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CTS	---	.019	.019	.017	.015	.014	.013	.012	.012	.013	.015	.017	.019
PAT	°C	18.0	18.0	18.0	16.0	14.0	7.0	5.0	5.0	10.0	13.0	18.0	18.0
RDC	°C	7.5	7.5	2.5	-1.0	-5.5	-16.0	-26.0	-26.0	-5.5	-1.00	2.5	7.5
RDM	°C	.55	.55	.75	.60	.75	.95	1.25	1.25	.75	.60	.75	.55
TLN	°C per 1,000 feet	1.1	2.0	2.5	3.1	3.9	3.6	3.8	3.6	3.5	2.1	1.3	0.8
TLX	°C per 1,000 feet	1.1	2.0	2.5	3.1	3.9	3.6	3.8	3.6	3.5	2.1	1.3	0.8

Parameter	Units	Value of parameter for indicated hydrologic response unit								
		1	2	3	4	5	6	7	8	9
				Williams Draw						
CTX	---	13.0	13.0	13.0	13.0	13.0	13.0	---	---	---
COVDNS	percent	30	30	35	25	35	25	---	---	---
COVDNW	percent	15	15	20	20	10	20	---	---	---
DSCOR	---	1.75	1.75	1.55	1.00	2.10	1.20	---	---	---
RECHR	inches	.0	.0	.0	.0	.0	.0	---	---	---
REMX	inches	1.3	1.3	1.3	1.3	1.3	1.3	---	---	---
RNSTS	inches	.05	.05	.05	.05	.05	.05	---	---	---
RNSTW	inches	.05	.05	.05	.05	.05	.05	---	---	---
SCN	---	.0	.0	.0	.0	.0	.0	---	---	---
SCX	---	.02	.02	.02	.02	.02	.02	---	---	---
SC1	---	.0	.0	.0	.0	.0	.0	---	---	---
SEP	inches per day	.1	.1	.1	.1	.1	.1	---	---	---
SMAX	inches	6.65	6.65	6.65	6.65	6.65	6.65	---	---	---
SNST	inches	.02	.02	.02	.02	.02	.02	---	---	---
SRX	inches	2.0	2.0	2.0	2.0	2.0	2.0	---	---	---
TNAJ	°C	.0	.0	.0	.5	.0	.8	---	---	---
TRNCF	---	.80	.78	.80	.60	.80	.59	---	---	---
TXAJ	°C	.0	.0	.0	.5	.0	.8	---	---	---

Table 10.--*Values for model parameters used in application of precipitation-runoff modeling system to Williams Draw and Bush Draw basins*--Continued

Parameter	Units	Value of parameter for indicated hydrologic response unit								
		1	2	3	4	5	6	7	8	9
					Bush Draw					
CTX	---	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
COVDNS	percent	30	25	30	30	35	25	25	35	25
COVDNW	percent	15	20	15	15	20	20	20	20	20
DSCOR	---	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
RECHR	inches	.0	.0	.0	.0	.0	.0	.0	.0	.0
REMX	inches	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
RNSTS	inches	.05	.05	.05	.05	.05	.05	.05	.05	.05
RNSTW	inches	.05	.05	.05	.05	.05	.05	.05	.05	.05
SCN	---	.0	.0	.0	.0	.0	.0	.0	.0	.0
SCX	---	.02	.02	.02	.02	.02	.02	.02	.02	.02
SC1	---	.0	.0	.0	.0	.0	.0	.0	.0	.0
SEP	inches per day	.1	.1	.1	.1	.1	.1	.1	.1	.1
SMAX	inches	6.65	6.65	6.65	6.65	6.65	6.65	6.65	6.65	6.65
SNST	inches	.02	.02	.02	.02	.02	.02	.02	.02	.02
SRX	inches	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
TNAJ	°C	.0	.0	.0	.0	.0	.0	.0	.0	.0
TRNCF	---	.76	.76	.76	.76	.76	.76	.76	.76	.76
TXAJ	°C	.0	.0	.0	.0	.0	.0	.0	.0	.0

Values for nondistributed parameters or parameters for which only one value was used in the present study

Parameter	Units	Value	Parameter	Units	Value
BST	°C	7.1	RCF	---	0.43
CTW	---	.25	RCP	---	.14
DENI	---	.10	RDMX	---	.85
DENMX	---	.45	RES	---	.0
EAIR	---	.757	RESMX	---	1.0
FWCAP	---	.04	REXP	---	1.0
GSNK	---	.001	RMXA	---	.60
PARS	---	.44	RMXM	---	.10
PARW	---	.50	RSEP	inches per day	.01
RCB	---	.20	SETCON	---	.10

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